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When experts disagree (and better science won't help much): Using structured deliberations to support endangered species recovery planning

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ABSTRACT

Progress on recovery plans to conserve endangered species is often blocked due to the lack of an effective framework that technical experts and other knowledgeable stakeholders can use to examine areas of agreement or disagreement about the anticipated effects of management actions. Multi-party, multi-interest resource management deliberations, although increasingly common, are difficult in the context of recovery planning due to the range of potentially affected environmental, economic, and social concerns. These deliberations are further complicated by frequent disagreements among technical experts about how to identify and address various sources of biological uncertainty. We describe the development of a decision-aiding framework as part of an inter-agency plan to assist recovery of endangered Gulf of Maine Atlantic salmon (*Salmo salar*), using a structured decision making approach that encouraged constructive deliberations based on rigorous analysis. Results are summarized in terms of developing an explicit set of management objectives, clarifying and prioritizing hypotheses concerning barriers to recovery, comparing alternative management initiatives in light of biological uncertainty, and incorporating resource constraints to generate preferred sets of actions. Overall, the use of a structured approach to making recovery decisions improved inter-agency cooperation and facilitated dialogue, understanding, and agreement among participating experts. It also helped to create a defensible basis for further internal discussions as well as for communicating with external stakeholders, including resource users and political decision makers.

1. Introduction

Efforts to protect threatened and endangered (T&E) species are among the most important of all tasks assigned to environmental managers. Aided by passage of the Endangered Species Act (ESA) in the United States in 1973 and the Species at Risk Act (SARA) in Canada in 2002, legal support for the protection of T&E species is a cornerstone of North American environmental policy. Yet the number of T&E species continues to climb at an alarming rate, whereas the number of species removed from the endangered and protected lists is disappointingly small (Scott et al., 2006).

This paper emphasizes the need for a defensible and structured decision-aiding framework as part of an effective recovery planning strategy for threatened or endangered species. We focus on development of a framework to aid recovery of endangered Atlantic salmon (*Salmo salar*) populations in the northeastern United States. During the period 2007–2010, the first two authors (Gregory and Long) were asked to assist an inter-agency group of scientists (which included the other authors) charged with developing and evaluating competing recovery strategies, as a precursor to the subsequent creation of a formal recovery plan. The goal of these meetings was to assist senior managers and staff in establishing a defensible basis for moving forward with implementation of a scientifically sound recovery framework and a broadly accepted, collaborative management strategy.

Optimism initially was at least as scarce as wild Atlantic salmon, in part because previous inter-agency management experiences had resulted in frustration, a widespread lack of trust, and

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substantial conflict. Use of a structured decision making process (Gregory et al., 2012) led to the development of an explicit set of management objectives and evaluation criteria and an improved understanding of hypotheses about key barriers to recovery. This foundation provided a basis for effective inter-agency cooperation and has been central to subsequent recovery planning efforts, leading (in March, 2011) to inter-agency adoption of an official Atlantic Salmon Recovery Framework. A significant key to this success was recognition of the limited near-term role of improved scientific results as compared to potential insights from discussions among participating experts and the adoption of improved, and broadly supported, evaluation and decision-making processes. Special attention was given to methods for estimating the costs and benefits of management actions under conditions of substantial biological uncertainty.

This paper provides a brief introduction to the context for species recovery decisions, discusses key analytic and deliberative issues, and provides an overview of the approach used in a series of Atlantic salmon recovery framework workshops to address disagreements among participating scientists and resource managers and to successfully develop broadly supported recommendations for near-term mitigation and research activities. We also provide general suggestions for encouraging inter-agency coordination and more effective decision making as part of endangered species recovery planning efforts.

2. A decision making perspective on recovery planning

2.1. General issues in species recovery planning

The issues associated with recovery of a threatened or endangered species are complex. The objectives advanced to guide conservation efforts are often vague, inconsistent, and controversial (Tear et al., 2005). Scientific opinions on the benefits of management initiatives are rarely marked by broad agreement; as Ludwig commented a decade ago, often "there are no clearly defined objectives and a plethora of mutually contradictory approaches, each of which is plausible in a particular frame of reference" (Ludwig, 2001). Legal frameworks provided for species conservation remain ambiguous, particularly with respect to balancing biological and ecological considerations with economic, social, or cultural concerns. Public support in North America for high-visibility T&E species (e.g., bald eagles, California condors, grizzly bears) generally has been strong, but far less concern typically is given to less charismatic species or to the protection of their respective habitats. Political support, at national and international levels as well as from regional and local governments, is mixed and this leads to conflicting messages and inconsistent funding for critical studies and institutions.

The resulting mix of multiple players, social controversy, and biological uncertainty results in many recovery-planning initiatives becoming stalled, leading to frustration on the part of scientists, resource managers and technical staff. In many cases, lack of progress on recovery planning is due to disagreements about preferred management strategies between participating scientists, managers, and policy staff of the agencies or national governments they represent. At other times promising initiatives are blocked by other stakeholders, either through political means or through court actions and litigation, who perceive their interests as being ignored or given limited emphasis. In many cases, management policies and political choices will emphasize short-term economic efficiency over what are viewed as competing ecological or social objectives (Healey, 2009). Important considerations, such as those concerned with governance and equity, typically are considered to lie outside the zone of influence or mandate of most recovery initiatives.

Despite these many problems, there are numerous examples of success in salmon conservation efforts. In our opinion, the key to moving forward and successfully implementing recovery plans is often the development of decision-making processes that can facilitate focused discussions among the affected parties and effectively address a broad mix of concerns. Instead, most species recovery efforts continue to emphasize the development of an improved scientific basis for making technical decisions. Although we fully acknowledge the need for rigorous science as part of recovery planning actions, we argue that many recovery-planning efforts are stalled not by deficiencies in science but by deficiencies in how the values of the different interests are integrated into recovery planning efforts.

At a fundamental level, the initiating force for efforts to conserve or protect any T&E species is human values, not science. This perspective is highlighted as part of conservation efforts targeting salmon because of their important food, cultural, and health benefits, both to the general population and to coastal and indigenous communities. People care about the protection of species for a variety of reasons—because they are part of the natural environment, because they yield economic or social benefits, because they are part of heritage that should be passed on to future generations—and science can help point the way to effective recovery plans. But the results of scientific studies cannot, in isolation from the careful assessment of values, provide the information needed to make decisions about how much protection or development is desired, how much uncertainty in outcomes is acceptable, or how tradeoffs should be made across different management objectives (Gregory et al., 2006).

2.2. Issues in Atlantic salmon recovery planning

Ocean-run salmon are iconic and highly valued; because of recent population declines, efforts to protect T&E runs of salmon are underway throughout the world. Declining salmon runs in the northern Pacific Ocean, for example, have received substantial attention from scientists and resource managers in many North American and Asian pacific-rim countries (Bottom et al., 2009). Atlantic salmon have been the subject of extensive management efforts in the United States and Canada as well as several countries in northern Europe (Haapasaari and Karjalainen, 2010). Yet due to an unusual anadromous life cycle—returning to natal streams to spawn after several years spent in the ocean—salmon also face an extensive set of risks: changes to ocean temperatures or currents; a variety of threats arising from marine pollution; urban and industrial growth, which impacts estuaries and the interface of oceans and coastal rivers; hydroelectric dams that block access to rivers and streams; by-catch as part of other marine fisheries; and extractive resource developments that affect water quality and temperature. Mitigation and enhancement efforts that address these risks face the added challenge of a species with a 2–5 year return cycle, which means that studies designed over 4–5 generations of salmon returns could run for decades.

The Atlantic salmon (ATS) recovery program in the Gulf of Maine is a collaborative management effort among three primary agencies: the U.S. Fish and Wildlife Service (FWS), the National Oceanographic and Atmospheric Administration (NOAA)—the parent organization of the National Marine Fisheries Service (NMFS)—and the Maine Department of Marine Resources (DMR). The fundamental goal of recovery efforts is to increase the abundance and persistence of wild Atlantic salmon spawning in designated Gulf of Maine rivers (NMFS, 2011). A distinct population segment (DPS) was designated under the federal Endangered Species Act in November, 2000 for the Gulf of Maine (GoM) and its associated watersheds; at the time there were eight known populations within the DPS, and in 2006 an estimated 79 adult wild salmon returned. In 2009 the range of the DPS was expanded to include three large rivers in Maine, the Androscoggin, Kennebec and Penobscot; whereas historical populations numbered in the hundreds of thousands, recent annual returns to this expanded DPS are only about 3000. The decision to expand the DPS was controversial (largely due to economic and political factors) but clearly supported under the ESA: Atlantic salmon in the larger river systems are closely related to those in the smaller coastal rivers and there exists broad agreement among biologists that a wider geographic focus is necessary to improve the feasibility and potential for success of recovery actions.

Substantial progress has been made over the past decade in understanding the biology of GoM Atlantic salmon and in developing a conservation hatchery supplementation program. However, population numbers for returning wild salmon have not improved measurably and significant challenges remain with respect to development of an effective recovery program. These issues were highlighted in two constructively critical reports conducted by the National Research Council (NRC) and by Sustainable Ecosystems Institute (SEI). The NRC report (2004) noted that there remain substantive disagreements among cooperating scientists from the three participating agencies. As a way to move forward, NRC recommended that recovery planning efforts for Atlantic salmon adopt a systematic, structured approach to making management decisions that focuses on understanding critical uncertainties and developing strategies to address key sources of ecological risk. The SEI report (2007) noted that the GoM Atlantic salmon recovery program lacked a clear decision making framework to integrate management goals and strategies, including research and mitigation activities, monitoring, stock assessment, and hatchery production.

In 2007 the Atlantic Salmon Management Board (MB), composed of representatives from the three lead agencies (in cooperation and consultation with the Passamoquoddy Tribe and the Penobscot Indian Nation), was directed to explore a new collaborative approach for moving forward with recovery actions. One aspect of this response involved a commitment to establish a single recovery strategy, implemented by the three resource agencies (with support from the Tribes) and with both management and research activities clearly linked to identifiable objectives. As part of this reorganization it was proposed that several teams of staff scientists be established (under direction of the MB) to develop specific plans for addressing priority hypotheses relating to DPS recovery. It was also suggested that outside help be sought for developing an overall decision making framework for Atlantic salmon recovery, based on methods drawn from structured decision making (SDM) and decision analysis.

Five considerations were highlighted as key to the development of a successful recovery framework.

2.2.1. *Restore fully functional ecosystems*

Populations are now at the point where most experts consider short-term supplementation through conservation hatcheries to be essential and long-term recovery (in terms of achieving self-sustaining wild populations) to be extremely challenging. Even with supplementation, and depending on the choice of quasi-extinction threshold, the most recent official “status review” report estimates that the likelihood of ATS extinction within the next 100 years ranges from 19% to 75% (Fay et al., 2006). Along with the legal mandate through the ESA (which is to recover the ecosystems upon which listed species depend) there is a public desire to ensure recovery of the species, which will result in benefits to the ecosystem and to society along with various costs (e.g., changes to land and river use related to improvements in habitat connectivity). Yet efforts to date have had limited success and recovery plans are expected to remain controversial; Hilborn (2007) recently noted that “No region in the US has generated more political controversy over fisheries policy” than New England. Yet with returning numbers of wild salmon at historically low levels, short-term actions are urgently needed if salmon in the GoM are to avoid extinction.

2.2.2. *Recognize tradeoffs across multiple dimensions of value*

The need to strike a balance across different management objectives complicates how biological and ecological considerations are addressed. In a perfect world for ecologists and conservation biologists, with the sole objective of improving conditions for Atlantic salmon, recovery considerations would guide construction of an official plan. Yet “real-world” recovery planning is rarely so straightforward (Wilson et al., 2009). Instead, there are competing demands for resources: what to one group is an important species, in need of protection under state and national laws, to another is incidental collateral damage resulting from an essential economic activity. Similar conflicts extend to habitat required by the species: cleanup of an estuary or re-opening blocked spawning and rearing areas along a river are often obvious actions to take on behalf of salmon, but the suggested cleanup may be prohibitively expensive or the removal of passage barriers may adversely affect other important uses of the river (e.g., including, for the state of Maine, the generation of electric power from hydro dams or the provision of irrigation for agriculture).

2.2.3. *Address biological uncertainty associated with recommended actions*

Probabilistic estimates of improvements in abundance, genetic diversity, or other key variables are often subject to wide ranges. Both the lack of quality data and the high costs and long time periods usually associated with its acquisition mean that expert opinions are, of necessity, relied on when creating recovery strategies and predicting their anticipated success. Yet eliciting and aggregating the judgments of experts is challenging, and key issues may be thought about quite differently by different experts; for example, experimental types of habitat improvement or artificial rearing (e.g., through a conservation hatchery) may be recommended by some biologists and opposed by others, not only on technical grounds (i.e., there may be significant disagreement as to the associated facts) but on the basis of different risk tolerances (i.e., the extent of uncertainty that is considered acceptable).

2.2.4. *Recognize and anticipate governance concerns*

Three different management agencies—the DMR, the FWS, and the NMFS—all share responsibility for conservation of Atlantic salmon. The FWS and NMFS also have trust responsibilities for Tribes. In addition, a diverse group of stakeholders and Tribes, along with local citizen groups and environmental organizations, have an interest in the health of salmon stocks and the progress of salmon recovery efforts. In the past, differences in legal authority, agency procedures and protocols, and conflicting biological expertise and advice have led to disagreements about the desirability of specified recovery actions and delays in making decisions.

2.2.5. *Recognize management and implementation concerns*

In addition to the three levels of administration (or four, including the Tribes) that contribute to ATS recovery planning, there is a Policy Board that provides broad policy direction and commits resources; a Management Board that formulates recovery priorities, seeks consistency in both short- and long-range planning for recovery actions, and allocates resources in response to the strategic consideration of recovery priorities, and staff who are tasked with developing detailed work plans as well as overseeing their implementation and monitoring the consequences of actions. All three levels reviewed the draft Recovery Framework and recognized that any recovery plans recommended by expert participants would need to be shared with, and revised by, other stakeholders before being brought to the attention of political decision makers at the federal, state, or local level.

3. Methodology

3.1. A decision-aiding approach to structuring recovery planning

Discussions over several years among staff of the responsible agencies—including resource managers, fisheries biologists, ecologists, and other scientists—failed to result in clear priorities for ATS recovery. They did result in long lists of potential recovery actions; however, these actions are highly diverse: some are likely to generate benefits in the short-term whereas others will require many years or decades; some actions are inexpensive whereas others are costly; some actions could easily be implemented whereas others impinge on established uses of terrestrial or marine habitats; some actions are stand-alone whereas the success of others requires complementary activities to precede or follow. The lack of organization means that comparisons across actions make little sense. This is problematic because, for ATS and other T&E species faced with sharp declines in population levels, urgent and unified action is needed to reduce the species' probability of extinction.

Structured decision making (SDM) approaches, recommended in the 2004 National Research Council review, combine the logic and analytical techniques of decision analysis (Keeney, 1982; Keeney and Raiffa, 1993) with insights from behavioural research (Slovic, 1995; Kahneman and Tversky, 2000) and applied ecology (Burgman, 2005). As a way to organize diverse sources of information and to integrate problem analysis with deliberation, SDM methods have been applied in the context of a variety of other species conservation problems (e.g., Conroy et al., 2008; Patrick and Damon-Randall, 2008; Gregory and Long, 2009) and are advocated by the U. S. Department of the Interior as a basis for the adaptive management of natural resources under conditions of uncertainty (Williams et al., 2007). The main contribution of an SDM approach is that it takes information relevant to the diverse considerations involved in species recovery planning—concerns relating to ecological, legal, implementation, uncertainty, governance, or management issues—and first organizes them as part of a single decision-focused plan that addresses both factual issues and values, then asks a series of context-specific questions concerning tradeoffs across potential recovery framework components: What are the underlying objectives of conservation efforts? What are the expected consequences of different management actions, and how should outcomes be measured? What confidence do scientists hold in proposed actions? Do agency affiliations result in biased predictions? To what extent should ecological initiatives be constrained by economics? Is the level of agreement among experts sufficient to implement selected actions?

To answer these questions an SDM process typically seeks to organize information relevant to a recovery plan through several interlinked and iterative steps (see Fig. 1). The intent is to foster collaborative analysis and dialogue among participating stakeholders, with the goal of developing management alternatives responsive to the expressed concerns and that address both short- and long-term goals of management agencies. Techniques used to encourage deliberations and help structure key decisions (described in more detail in Section 4, in the context of Atlantic salmon recovery planning) include (a) consequence tables, which link alternatives and their anticipated consequences to objectives; (b) influence diagrams, used to represent the causal relationships among decisions, external factors, uncertainties and outcomes; (c) strategy tables, used to stimulate creative thinking about management actions; and (d) probability assessments, used to characterize the uncertainty associated with key concerns (see Gregory et al., 2012).

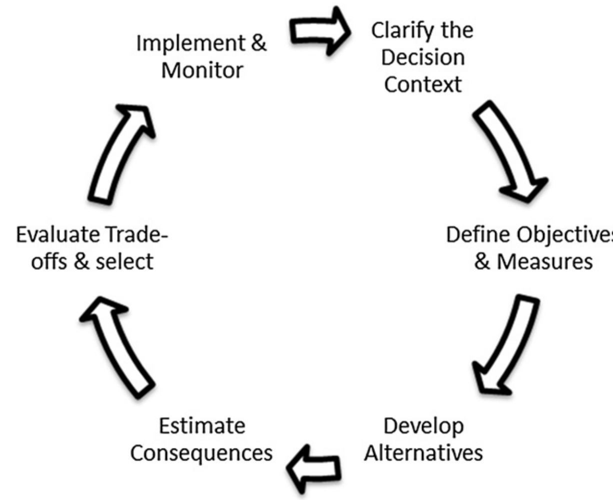

Fig. 1. Steps in a structured decision making approach.

3.2. Decision framework development

As a first step to creation of an official recovery plan, the Management Board invited 5–7 scientists and managers from each of the three lead agencies to a series of recovery framework development workshops. The goal (and the focus of this paper) was to lay the groundwork for a draft recovery framework acceptable to all three management agencies, which would then be reviewed by the Tribes, members of the public, and other affected stakeholders. A structured decision making process was introduced with the intent of overcoming years of limited coordination, lack of trust, and poor communication, resulting in frequent disagreements among agency staff. The MB was therefore faced with three primary challenges: to determine an appropriate balance among the various 'funding-worthy' areas of short-term recovery activities (e.g., predator control programs in rivers or estuaries, barrier removal programs in rivers, water quality correction programs, physical habitat restoration options, and marine fishery regulation enforcement), to prioritize between short- and long-term recovery activities (i.e., between management and research), and to create an outline for moving forward that would be supported by both scientists and managers from the three lead management agencies.

The participants also all agreed that estimating the benefits of recovery actions in terms of potential numbers of additional adult returns was essentially impossible. Instead, it was decided that a more helpful and realistic way to conceptualize the various recovery plan activities was to link the future time frame required for an action to its expected benefits, since this would create a sequence of recovery decisions and estimated outcomes. Activity areas were deemed "funding worthy" if they could beneficially affect at least one of the following four areas:

- short term opportunities to begin increasing the natural production of smolts almost immediately (e.g. barrier removal programs)

- research that might lead to highly-valuable, long term conservation opportunities (e.g. marine research programs)
- necessary short-term but, in the long term, unsustainable interventions (e.g. conservation hatcheries) that could help prevent extinction of ATS before other activities reverse its decline more sustainably, or
- activities whose costs are expected to be low relative to their benefits (characterized as "low-hanging fruit"), thereby providing visible recovery benefits while freeing limited resources.

An important subtext was the need to understand and openly discuss the pros and cons associated with creating a decision framework to guide the evaluation of diverse recovery actions. Several participating scientists expressed concerns that development of an explicit framework could hinder their ability to pursue "pure" science. Others doubted whether a new system was required, since the current division of tasks between managers and scientists appeared to be working fairly well. Other participants disagreed and cited the SEI and NRC reports as having noted, in strong language, the need for an integrative decision making framework and improved coordination, both across the three lead management agencies and between resource managers and scientists. Several participants also argued eloquently for adoption of a fresh, decision-focused approach so as to move beyond the conventional incremental tweaks to the status quo. Ultimately, an argument in favour of developing an improved decision making framework for Atlantic salmon recovery activities gained broad support, reflecting the agreed-upon need to use a single set of management objectives and criteria so as to better integrate activities and funding allocations across the three agencies and to provide a sound basis for moving forward with development of a recovery framework.

4. Results

This section uses the six decision making steps shown in Fig. 1 to summarize the sequence and results of the Atlantic salmon recovery framework discussions. Our focus is on ways in which analysis was used to encourage dialogue among representatives from the three management agencies and, in cases where significant differences of opinion existed, to explore ways to address or resolve these differences as part of a mutually supported recovery planning framework.

4.1. Problem definition

Five areas were identified as particularly important to the development of a recovery framework for ATS.

1) Create a clear set of management objectives to guide recovery actions.
2) Distinguish between research and management activities. The former are focused on learning and reducing uncertainty, and are designed to either increase the probability that an action will succeed or to increase experts' understanding of, and confidence in, its success. The latter are focused directly on aiding near-term Atlantic salmon recovery.
3) Develop a better understanding of hypotheses that address barriers to ATS recovery.
4) Encourage dialogue among scientists from the three lead management agencies to identify key areas of agreement and disagreement, with a focus on articulating the implications of biological uncertainty for the evaluation of proposed management actions.
5) Develop an initial framework for linking identified recovery priorities and leading hypotheses to near-term management actions (recognizing that subsequent contributions from other stakeholders will revise and inform this process).

4.2. Identifying recovery objectives[2]

The foundation for decision-focused recovery planning is agreement on the definition of objectives (which later will be used to evaluate candidate management strategies). This objectives-setting phase of a structured decision making approach takes time, and our efforts to clarify the objectives expressed by participating scientists and managers were more than occasionally met with complaints (along the lines of " . . . can't we just get on with it?"). Yet we agree with Wilson et al. (2009; 258), whose review of setting conservation priorities concludes that " . . . problem formulation is critical. Without a clear definition of goals . . . decisions are unlikely to be cost-effective, and outcomes cannot be evaluated."

Participants in these ATS recovery framework discussions agreed to distinguish between fundamental objectives (those things of ultimate concern to the Atlantic salmon recovery program) and indirect or means objectives (which provide ways to achieve a fundamental objective; see Keeney, 1992). Prior to the start of these discussions, fundamental objectives had been defined as an increase in the abundance and the distribution of wild Atlantic salmon populations within the DPS. Other objectives suggested during the initial workshop discussions included species persistence, financial cost, genetic diversity, healthy ecosystems, urgency, collaboration, flexibility (in terms of adaptive management), and ease of implementation (governance, politics). Consistent with the iterative nature of an SDM decision-making process, further dialogue among participants led to agreement that neither abundance nor distribution should be used directly as the fundamental endpoint for ATS recovery activities; there exists too much uncertainty (particularly with respect to marine survival) to estimate fish abundance, and effects on distribution can only be assessed at a project level once specific rivers are selected for specified actions.

After additional discussion, two new fundamental objectives were agreed to by all participants: minimize the short-term probability of ATS extinction, and maximize the long-term probability of recovery of wild ATS fish. Much of the debate focused on the identification of sub-objectives, with participants recognizing that recovery efforts require not only the increased abundance of wild salmon over a wide geographic range (i.e., distributional concerns) but also access to a functioning ecosystem and sufficient diversity (in genetics, life history, and morphology) to withstand natural ecosystem variability. Although it was noted that many of the specific actions needed to minimize the short-term probability of extinction will differ from actions taken to maximum the long-term probability of recovery, these same four sub-objectives—increasing abundance, maintaining genetic diversity, increasing distribution

[2] In the decision analysis literature (Keeney, 1982), the term "objective" is used to refer to the identification of a valued component and a preferred direction of movement, e.g., "minimize the long term probability of extinction." This usage is subtly different in much of the fisheries management literature, where objectives are typically stated in terms of targeted outcomes such as "ensure salmon populations are maintained to X condition." When setting regulations, clearly defining targets is essential. However, for the creation and evaluation of different recovery options, the goal is to examine the multi-objective impacts associated with one approach versus another. For this reason, we employ the decision analysis convention when introducing objectives.

(both within and across rivers), and improving ecosystem functioning (including habitat connectivity and effects on diadromous or migratory fish populations)—were included (albeit with different weights) as part of both short- and long-term recovery program objectives.

4.3. Using recovery hypotheses to identify management alternatives

To initiate an objectives-based discussion of possible management alternatives, participants focused on a discussion of hypotheses that addressed the range of factors thought to inhibit recovery of ATS. Extensive previous work had been completed on hypotheses to explain population declines, including a comprehensive list of hypotheses developed in 2000 (Cairns, 2001). Although this listing is scientifically rigorous, it was recognized that it does not translate easily into management decisions: the list mixes issues of different recovery magnitude and different probability of success and includes potential activities with widely varying time and cost implications.

Significant differences of opinion existed among the participants regarding how the different recovery hypotheses could best be organized. Options included organizing actions by source of threat (e.g., dams, marine survival, conservation hatcheries), by location (e.g., downeast v. Penobscot v. mid-coast), or by limiting factors (e.g., water quality, predation, hatchery stocking, marine survival, passage, aquaculture, and habitat). Recognizing these differences in perspective led to the development of influence diagrams (see Fig. 2) showing impact causes, their primary mechanisms, and possible limiting factors. Similar decision aids are often used to visually represent key relationships as part of environmental management decisions (Howard, 1988). In this case, we highlighted mechanisms that connect different recovery actions and their consequences as a way to encourage open discussions among participating scientists.

Discussions about the mechanisms column helped to capture and clarify participants' initial assessments of the uncertainty associated with the hypotheses covering causal relationships. For example, the relation between turbines in dams and direct fish mortality is relatively clear and there was little disagreement among participants. In contrast, the relation between reductions in marine survival of adult salmon and a variety of natural causes is subject to substantial uncertainty and most participants agreed (as

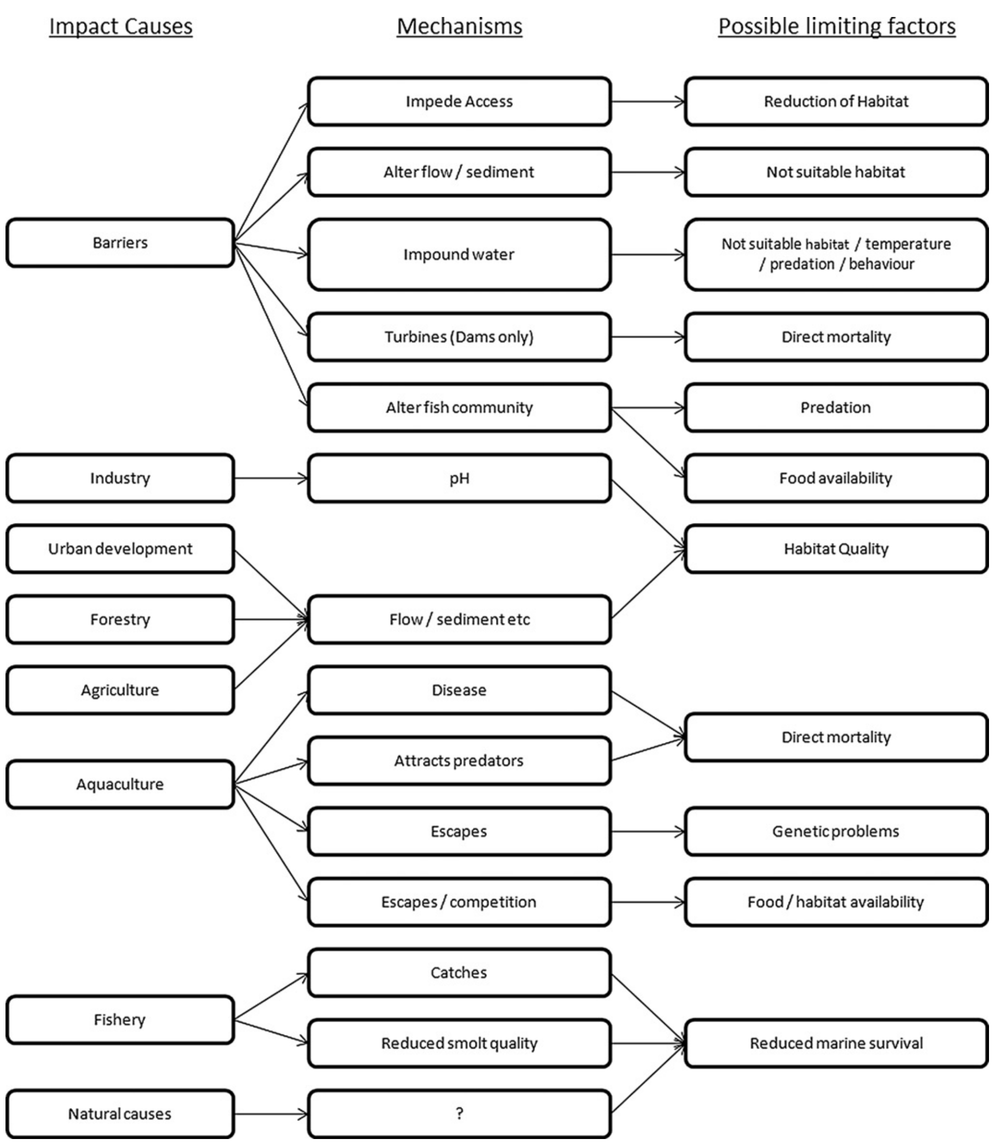

Fig. 2. Example ATS influence diagram.

shown by the question mark in this column) that so little is known about the effects of management actions on marine survival of salmon that it is difficult (except in broad terms) to characterize the anticipated gains associated with related mitigation or research initiatives.

To review these different hypotheses in detail, a small number of "action teams" were created to generate and review detailed recovery activities that address the leading "barriers to recovery." Participants assigned themselves to one of the five groups, which focused on recovery initiatives to be undertaken in freshwater (rivers), estuarine and coastal areas, the marine environment, or in conservation hatcheries (with a focus on either increasing adult spawners or maintaining genetic diversity). For each of these activity categories, participants were tasked with creating detailed lists of possible actions (e.g., what could be done to improve the marine environment, to maintain genetic diversity, etc).

Strategy tables were introduced as a technique to aid discussions within each Action Team and to help move discussions from a focus on projects (i.e., individual actions relating to single hypotheses) to strategies (i.e., multiple actions relating to multiple hypotheses). Column headings (see Table 1) denote the leading types of management activities; these mirror the areas of emphasis for each of the action teams. Rows depict different levels of management focus, with relatively less intensive levels of activity shown at the top of the column and more intensive levels at the bottom. Alternative recovery strategies could now be generated, by combining one or more management activities from each of the designated columns, and compared in terms of their contribution to each of the fundamental objectives. As one example, Table 1 depicts the 'status quo' strategy alternative, whose main components are shown by the circled items.

An important requirement in selecting and comparing these strategies was the accurate definition of existing (baseline) programs and the identification of activities considered to be mandatory for managers (such as stock assessments) as part of legally required "due diligence." One option that was raised (and initially favoured) by some participants was to continue to fund these activities and to consider only the additional actions that could be undertaken with remaining, discretionary funds. Another option was to consider all activities as discretionary, following the logic that existing funds may be insufficient to achieve even minimum recovery goals and, as a result, decisions will need to be made about allocating funds across essential recovery activities. After discussion, this latter viewpoint was agreed to by all participants, which implied that funding for assessments was to be included as part of the other categories.[3]

4.4. Understanding the expected consequences of recovery actions

The work noted thus far—covering problem bounding, identifying and measuring objectives, and developing alternatives—is a prelude to consideration of the estimated consequences of the different management initiatives. At the outset it was recognized that this was likely to be both the most important and the most problematic phase of the recovery framework development process, for two reasons: the difficulties associated with estimating the benefits of discrete recovery actions and, linked to this, the biological and institutional uncertainty associated with the anticipated effectiveness of a specified initiative. As a result, we discuss these two aspects of the recovery framework in some detail, following a brief process review.

4.4.1. Process considerations relating to estimating consequences

The goal of the consequence deliberations was to efficiently review the consequences of strategy alternatives in a way that would encourage dialogue and help the participating scientists from the three agencies to reach agreement on the expected outcomes of proposed management actions. In addition, it was recognized that the analyses of consequences should be documented clearly because they later would be communicated to, and scrutinized by, members of the public, other stakeholders, and elected state and federal officials. Seven considerations were emphasized:

- the expected time required before an action leads to an identifiable response; this is important because of the urgency associated with recovery actions in the GoM.
- the desired sequencing of actions: what should be done first in order to facilitate or lay the groundwork for related and subsequent actions.
- risk tolerances, which vary across management actions and, perhaps, across GoM salmon stocks. For example, higher levels of risk tolerance may be required for actions undertaken in the marine environment due to the lower confidence associated with marine initiatives.
- the tradeoffs that exist within each category of management actions. For example, conservation hatcheries may result in both higher levels of risk to wild fish (by increasing competition for scarce habitat or food resources) and lower risk levels (by helping to reduce pressure on wild fish from predators).
- the confidence with which consequence estimates are made by scientists.
- the anticipated financial costs of implementation, assessment and monitoring, and evaluation of the recommended recovery actions.
- research benefits and learning, including reductions in uncertainty through additional studies, monitoring, or adaptive management initiatives.

In addition to using strategy tables to communicate the design of alternative management strategies, the use of an SDM approach allowed the MB to provide guidance to action teams on specific issues such as the desired relative ratio of short versus long term projects (for example: "ensure that at least 50% of value of the freshwater projects will be on self-sustaining projects") or the desired geographic scope of proposed activities (for example: "broaden the geographic scope of freshwater projects").

4.4.2. Assessing the benefits of recovery actions

Many initiatives designed to aid recovery of an endangered species lack a clear framework for assessing and comparing the different benefits of alternative plans.[4] Our goal was to develop a "common currency" for estimating benefits that would facilitate the comparison of different project-level suites of activities (recognizing that it would be imperfect and require refinement over time). Although participants from all three agencies agreed

[3] In hindsight, this decision was helpful in that it allowed for the comprehensive depiction of alternative strategies, inclusive of all activities, and thus facilitated the development of a coordinated and comprehensive set of recovery plan alternatives.

[4] Conceptually, the overall benefits of conservation efforts are often expressed in terms of a reduction in the probability associated with the extinction of a species. For ATS, as for many other endangered species, this vague expression of benefits provided little guidance to resource managers charged with development of an explicit recovery framework and little traction with either public or political stakeholders.

Table 1
Example strategy table ("Status Quo").

Level of activity	Marine	Estuary	Fresh water (smolts)	Conservation hatchery (spawners)	Conservation hatchery (genetics)
Low	Minimal presence at NASCO and ICES	Maintain minimum Sec 7 & 10 presence	Maintain minimum Sec 7 & 10 presence	Do nothing: deommission and release current stocks	Do nothing
	International collaboration	National collaboration	Regulatory outreach projects, absolute high priority only	Live gene bank	Frozen gene bank
Level of activity	Direct monitoring	Direct monitoring	Opportunistic habitat restoration, research	Active river-specific stocking (7 rivers); minimum hatchery activity evaluation	Maintain genetic broodstock mgt plan
	Direct experiments	Direct experiments	Targeted/strategic projects	Increase production, scope (#, lifestages, etc.); based on active hatchery activity evaluation	Expand genetic analysis of wild fish; extend beyond hatchery
High				Direct experiments	Direct experiments

that development of a single metric for expressing benefits would be helpful, it also was recognized that, because one action may influence several objectives, its benefits will vary depending on the perspective that is adopted. For example, there was widespread agreement that an action which produces more fish from a conservation hatchery would perform well on an objective that tracks "minimizing the probability of extinction in the short term" but there was substantial disagreement regarding its performance on objectives that concern longer term recovery viability or that address the maintenance of genetic diversity.

Several different possible approaches to benefits assessment were discussed. A first approach would simply ask the group to decide on a qualitative ranking of benefits importance (e.g. 1–5) for each proposed action or research project. Although the virtue of this approach is simplicity, its weakness is ambiguity because it bundles the many dimensions of 'importance' into one rating. A second option, with strong historical roots in the context of ATS recovery planning, involved development of a Threat Severity Index (TSI), with threats scored on a 1–3 scale as a function of impact magnitude and severity. However, several participants pointed out that—as the name suggests—the TSI was developed to characterize threats, not to evaluate actions intended to address those threats.

A key insight at this point was the recognition that the relative value of an action must include both its biological intent and its likelihood of success; otherwise, a project that is very unlikely to succeed, if directed at a wide range of geographic areas and life-stages, could be judged a prime candidate for scarce funds. This distinction encouraged participants to think about these two aspects of the problem independently; the *biological significance* of each targeted barrier to recovery and the *technical effectiveness* of the recovery action at mitigating the barrier.

In light of the importance of these two considerations, participants agreed to an explicit expert judgment process whereby the beliefs of each individual could be articulated and compared (Burgman, 2005). Group members were first asked, for each of the five major "barriers to recovery" activity areas, to provide their best judgment about the likely relative contribution of each category to recovery. Next, they were asked to weight the anticipated effectiveness of the associated recovery activities. These results were tabulated and normalized (so that participants' weightings would sum to 1) and then presented to the group for discussion, using two summary figures. Fig. 3 shows the range, 80% judgment intervals, and "most likely" estimates for the relative contribution to recovery for each of the five activity categories. Fig. 4 shows the same results for the judged (relative) effectiveness of actions that realistically could be undertaken by the MB within each activity category.

Important information is contained in these decomposed judgments, information that previously had not been available to the participating scientists.[5] First, the range of estimates varies considerably across participants. Looking at the 80% limits shown in

[5] The value of expert judgment elicitations is that they make explicit information held in the minds of participating individuals that otherwise would not be accessible as part of analyses. Despite the extensive use of expert judgments to help deal with uncertainties and the proven record of the technique (see Morgan and Henrion, 1990 or Meyer and Booker, 1991), scientists often complain—as they did here—that the explicit probabilistic articulation of their views will prove disruptive or interfere with their pursuit of good science. In fact, just the opposite is usually the case.

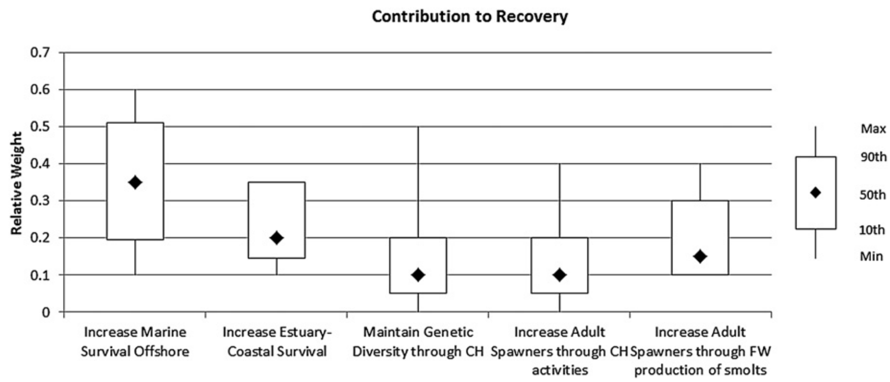

Fig. 3. Judged contribution to recovery of each activity category (showing minimum and maximum estimates, most likely or 50th percentile estimates, and 80% confidence interval).

Fig. 3, for example, differences in the assessed contribution to recovery of "increasing marine survival offshore" are substantial, with some participants giving this activity category an average weight of 0.2 (across the five categories) and others giving it a much higher weight; a weight of 0.5, for example, is equal to the combined contribution of all other activity categories. Second, both the relative contributions to recovery and the assessed effectiveness vary considerably across the five activity categories. However, there is general agreement among participants on at least the rank order (when shown as averages) across the categories, with "increasing marine survival" assessed as the most important category for recovery contribution (see Fig. 3) and conservation hatchery and freshwater activities (maintaining genetic diversity & increasing adult spawners) judged the most likely to be effective (see Fig. 4). Third, actions associated with the activity category showing the highest expected contribution to recovery (increase marine survival offshore) are given the lowest effectiveness score, whereas conservation hatchery activities are scored lowest in terms of their contribution to recovery but are given relatively high effectiveness scores. These results highlight one of the fundamental dilemmas facing the recovery framework process: the (arguably) leading cause of population decline, marine survival, is also the category for which management actions are least likely to be effective, whereas the expected benefits of conservation hatcheries, widely considered to be an effective and well-understood management tool, are rated quite low in terms of their anticipated contribution to recovery.

These findings stimulated development of another approach to benefits assessment, based on previous research using population viability analysis (or PVA; see Legault, 2005) to estimate abundance levels associated with recovered populations. The resulting model can be used to estimate extinction probabilities, including information on criteria such as population age structure. A working group, composed of a sub-set of participants from all three agencies (G. Mackey, DMR, coordinator; Tim Sheehan, NOAA; Mike Millard & John Sweka, FWS), was formed to fine-tune this approach and then report back to the larger group. The work of this sub-group led to development of a Biological Benefit Index (BBI) for Atlantic salmon recovery efforts, based on the anticipated effects of an action on each of the six salmon life stages. Two main elements are addressed:

- *Benefit scoring.* The benefits of a potential management action or research project to each life stage (egg, fry, parr, smolt, marine, and adult return/spawner) were rated by the group participants on an ordinal scale, from 0 (no or unknown benefit) to 3 (high benefit). These ratings also were informed by a matrix population model approach (Robertson, 2005), reflecting the probability of an individual fish at stage i and time t successfully transitioning to stage j at time $t+1$. The associated calculations make use of the concept of elasticities as a measure of the proportional sensitivity of the population growth rate to underlying survival and fecundity rates (Heppell et al., 2000), which are then multiplied by the amount of time spent in each transitional stage.
- *Importance weights.* The BBI calculation takes the assessment of the expected magnitude of the benefits of an action and weights it in terms of (a) the geographic area to which the

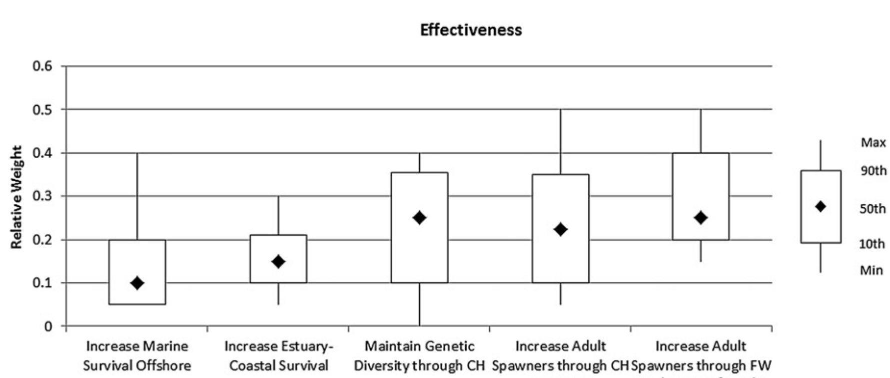

Fig. 4. Judged effectiveness of ATS actions to influence each activity category (showing minimum and maximum estimates, most likely or 50th percentile estimates, and 80% confidence interval).

approach is applicable, using (b) a multiplier based on a weighted sum of the affected life-stages. Weights placed on each life stage were hidden from users in order to avoid biasing the scores associated with each life stage; after these scores were compiled, participants were informed that (consistent with common sense) the highest weight was calculated for benefits associated with the marine life stage, whereas the lowest weight was calculated for fry and smolt life stages.

After extensive discussion, this BBI approach to benefits assessment was adopted by all the participating scientists and managers and used to assess and compare the biological benefits of the different proposed recovery activities.

4.4.3. Addressing uncertainty in consequence estimates

The other principal difficulty affecting benefit estimates of different management initiatives is that there is substantial biological uncertainty. This takes three major forms:

- uncertainty with respect to the extent to which initiatives undertaken in each action category, assuming they are successful, will be able to influence recovery of ATS populations. As shown in Fig. 3, there is more uncertainty associated with the extent to which activities intended to increase marine survival will influence ATS recovery than there is for increasing adult spawners through conservation hatchery activities.
- uncertainty with respect to the anticipated ability of management actions to make a difference with respect to each of the five identified activities categories. As shown in Fig. 4, the ability of activities funded through an ATS recovery program to influence marine survival is thought to be substantially lower than the program's ability to increase adult spawners through fresh-water smolt production.
- uncertainty with respect to scientists' confidence in their own judgments that the estimated levels of benefits associated with an action or strategy will be realized. To highlight this third source of uncertainty, an expert judgment process again was used to elicit information from participants, using a simple three-point scale of "very confident" (that judged benefits will be realized), "somewhat confident," and "long shot." These judgments were made by the respective action team members on each of the disaggregated activities proposed by their groups, which entailed substantial (albeit highly useful) effort and dialogue.

Discussions about how to address these different sources of uncertainty emphasized two additional considerations. First, although ATS recovery efforts are subject to many sources of uncertainty, not all of these are equally important: efforts to monitor or resolve uncertainty should take these differences into account (for example, using formal Value of Information analysis; see Runge et al., 2011). Second, participants discussed the implications of risk tolerance for the creation of a more robust overall recovery strategy. The information summarized in Figs. 3 and 4 reflects participants' technical judgments based on their understanding of the problem and the confidence held in their own knowledge. To directly aid recovery framework development, these assessments need to be complemented by value judgments concerning the acceptable level of risk associated with research or mitigation activities undertaken within each category (i.e., as recommended by each action team). For example, it may be necessary to accept a higher level of risk for activities designed to improve marine survival of salmonids, whereas for conservation hatchery activities it may be desirable to accept a relatively lower level of risk (in light of the short-term survival emphasis of hatchery actions). In addition, many participants emphasized the importance of developing robust recovery strategies, defined as ones reasonably likely to be effective in achieving their objectives over a wide range of both internal and external uncertainties (Lempert et al., 2006). Depending (in part) on their respective risk tolerances, managers could prefer a recovery strategy that was anticipated to be more robust with respect to ecological objectives even though achieving this might result in lower or less satisfactory results on some other valued objective, for example cost or implementation ease. This additional layer of tradeoffs was highlighted as part of the recovery framework discussions but additional and more specific analysis was left for the later stages of the recovery planning process.

4.5. Revising management alternatives in light of constraints

Up to this point the analysis had compared actions and scenarios in terms of ecological, economic, and other considerations but had not directly faced the reality of financial and personnel constraints. To help participants address resource constraints, a multi-year portfolio-building tool was developed (using an Excel Spreadsheet base) to aid each of the action teams in moving from desired strategies to portfolios of actions that address the designated objectives, consistent with available financial and personnel constraints (as measured by dollar expenditure limitations and designated "full-time equivalents," or FTEs). Our starting point was to develop consistent criteria for comparing the comprehensive lists of activities provided by each Action team. This evaluation was done on the basis of ten activity attributes, which together provide a relatively complete accounting of critical project characteristics. These included (in random order):

- the geographic extent of a project
- the percentage of occupied area
- the calculated biological benefits index BBI),
- the endurance of benefits (defined as whether an action would be self-sustaining or require ongoing inputs),
- the benefits timeframe (the degree to which benefits would be expected within the short term, defined as three salmonid return cycles),
- the initiation timescale (whether the start of benefits is expected within 1–3 years, 3–5 years, or only after five or more years),
- scientists' confidence that the benefits will be realized,
- social or political issues that might serve as "showstoppers,"
- genetic risks, to Atlantic salmon or to other species, and
- the possible benefits to other species.

As expected, differences were encountered across action teams in their approaches to the decomposition of projects and initial level of detail (e.g., some lists contained several hundred possible actions, others only 10 or 20); this served as a jumping-off point for further discussion, re-grouping of projects, and prioritization with the result that final project lists of all action teams were more easily comparable. In addition, because many recovery activities do not make sense to undertake unless they can be implemented at a sufficient scale, participants were asked to assess the minimum resource investment that would be required (in terms of both dollars and personnel) for this action to make a difference to ATS recovery. These judgments set a lower bound for levels of activity. In the same spirit, participants were asked to assess the benefits associated with the activity if, instead, a more generous level of resource investment were to become available. The pragmatic nature of these judgments brought home the "real-world" implications of the recovery decisions being made and, although

Table 2
Resource Allocations Across Alternative Portfolios of Actions.

	Alternative Portfolios (percent of budget allocation)					
	P1	P2	P3	P4	P5	P6
	"Status Quo"	"Marine Focus"	"Hatchery and Estuarine Focus"	"Freshwater and Hatchery"	"Freshwater Connectivity and Diadromous"	"Marine and Estuarine Focus- live gene bank"
1. Increase Marine Survival Offshore	10%	40%	5%	5%	5%	30%
2. Increase Estuary-Coastal Survival	6%	4%	20%	3%	16%	25%
3. Maintain Genetic Diversity through Conservation Hatchery	5%	5%	8%	10%	5%	4%
4. Increase Adult Spawners through Conservation Hatchery	32%	32%	50%	50%	32%	20%
5. Increase Adult Spawners via FW Production of Smolts	25%	17%	15%	30%	40%	19%
6. Population Monitoring Assessment[a]	22%	2%	2%	2%	2%	2%
	100%	100%	100%	100%	100%	100%

[a] For the Status Quo alternative, population monitoring and assessment was characterized separately; for the other alternatives, it was bundled (for reasons of efficiency and logic) into each of the five activity areas.

difficult, helped the decision making process to gain support from participating scientists and managers.

This refined database of potential projects and activities was now ready to use in creating an initial resource-constrained set of portfolios of actions. Table 2 shows the resulting "resource allocation" table, which uses percentage budget allocations to show the approximate maximum percent of resources available to a range of initial "bookend" portfolios, consistent with the legal and practical requirements of other activities. For example, participants judged that a maximum of 40% of overall resources (row 1) could be made available to help increase marine survival as part of the bookend "Marine Focus" portfolio, whereas 72% of annual resources (rows 4 and 5) could be made available to help increase adult spawners as part of the designated "Freshwater Connectivity" alternative.

4.6. Comparing recovery management alternatives

As part of an SDM (or other multi-attribute) approach, the estimated consequences of management alternatives are compared in terms of the specified objectives (Keeney, 1982; Gregory et al., 2012). For ATS recovery planning, this means that the six different sets of resource-constrained management actions shown in Table 2 need to be compared in terms of their ability to achieve progress on the fundamental recovery objectives and component sub-objectives: abundance, distribution, genetic diversity, and ecosystem function. Overall assessments for each portfolio therefore were made for minimizing the short-term probability of extinction [P(Ext)] and for maximizing the long-term probability of recovery of wild fish [P(Rec)]. Abundance was represented through the proxy indicator of the sum of the biological benefits index (BBI) for each of the action team areas (with a resource-weighted BBI used in the case of Estuary activities). For the other sub-objectives, different aggregate values were drawn from the available data. For example, the extent to which genetic diversity was different across the range of alternatives was indicated by the proxy of the average number of geographical units (SHRUs) being affected in each portfolio. The greater the geographical spread of the activity, the better the assumed performance on the objective of "genetic diversity." Similarly, "Ecosystem Function" performance was represented by the number of activities that were characterized as bringing "benefits to other species."

When normalized across the range of alternative portfolios, these summary results provided an indication of which alternatives might perform better (or worse) than others on each account. Since the goal is to identify a preferred portfolio of actions, this information is needed to help participating scientists and managers compare the anticipated outcomes of different actions on the expressed objectives and to clearly recognize trade-offs across the different portfolios of actions. However, two further steps were required. First, because not all objectives or sub-objectives are weighted equally—some differences in the expected level of changes in an alternative across selected management actions will be more important—participants were asked to provide explicit weights for the different objectives across the six alternatives. A simple weighted sum algorithm was used on a participant-by-participant basis to create an individual score for each alternative. This formed the basis of further discussions about which projects truly contributed to which objectives, to what degree, and the relative importance of the different objectives.

Second, it was recognized that each of the six portfolios that previously had been constructed were preliminary; in particular, because they were developed to illustrate and test the decision-aiding recovery planning framework, each focused on only a single consideration (e.g., the production of fresh-water smolts or improvements in marine survival). A necessary next step was to build several new portfolios that could draw from the strengths represented across several activity categories. After further discussion and review, four more portfolios were therefore suggested: one was developed through a coordinated, across-agency discussion (portfolio 7) and three others (portfolios 8, 9, and 10) were designed as sensitivity analyses, added to illustrate what might occur if budgets were to be increased. Using the interactive graph shown in Fig. 5, participants could immediately review the relative performance of these ten alternatives: the six equally funded portfolios (2–7) along with portfolio 1 (whose costs do not include stock assessment) and the three portfolios funded at higher levels (8–10). As might be expected, as funds increase so too do the overall scores. After further discussion, and aided by the recognition that the higher level of funding represented by portfolios 8, 9, and 10 was unlikely to be forthcoming, portfolio 7 was selected by participating scientists and managers from all three agencies as the preferred option.[6] This shared assessment marked significant progress in the development of a unified, across-agency approach to ATS recovery planning.

[6] Consistent with the iterative nature of the SDM process and the importance of subsequent input from other stakeholders and Tribes, this result served only as a test run of the "decision framework" approach and as an input to subsequent (and ongoing) recovery discussions, which also were able to reflect new information and the views of new participants in the recovery planning process.

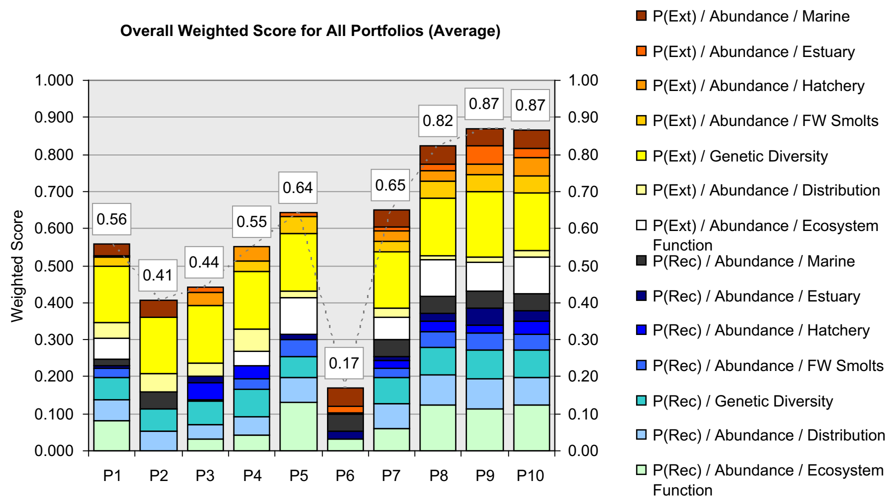

Fig. 5. Overall weighted portfolio scores. Note that only portfolios 2–7 are equally funded; Portfolio 1 does not include costs of stock assessment and portfolios 8–10 are funded at a higher level.

4.7. Encouraging recovery framework improvements through collaborative learning

An important process objective of the recovery-planning framework was to provide a flexible mechanism for incorporating learning. It was also recognized that, because of the uncertainty associated with the outcomes of many of the proposed recovery initiatives, learning over time would help to inform scientists and the MB about the utility of different recovery activities. Some of this information would come from ongoing monitoring efforts. Other information will come to light over time through input from other stakeholders. Additional information should arise from learning that takes place at other locations or as part of other related recovery programs.

Learning is central to any structured decision-making process: participants learn about the precise definition of recovery framework objectives, they learn about the value-based tradeoffs placed on the achievement of different objectives, they learn about each others' views and assumptions, and they learn about the extent to which different recovery activities might complement or interfere with each other (Gregory et al., 2012). By providing an overall structure for organizing the different sources of new information, one of the goals of a decision-aiding SDM recovery framework is to make learning transparent and easily accessible, so that it can more easily be incorporated into both participants' understanding of recovery issues and the plans advanced by the lead management agencies. A related goal of the explicit decision framework is to assess the anticipated benefits, costs and risks associated with learning, thus providing a perspective on whether the anticipated gains of a proposed research or adaptive management initiative are likely to exceed the associated costs (e.g., in terms of added time or expenditures). This perspective is consistent with the overall goal of developing more resilient management initiatives, now recognized to be an important consideration as part of many salmon conservation efforts in North America (Healey, 2009).

5. Conclusions

A decision-focused approach to recovery framework development differs fundamentally from what generally is done as part of most species conservation efforts, which can be characterized as science-based or biology-based approaches. A science-based approach is one that pursues opportunities for which " . . . the target is more—more protection, more restoration, and more management" (USGS, 2006). As one participant noted, the conventional model might also be characterized as a "trust me, I'm an expert" model: if participating scientists are allowed to do their jobs, and if managers from the respective agencies also are permitted to do their jobs, then things will work out as well as they can.

As noted in the 1996 National Research Council report "Understanding Risk" (NRC, 1996) as well as the 2004 report "Atlantic Salmon in Maine" (NRC, 2004), a science-focused model to recovery planning is open to criticism on several fronts: it lacks an explicit and transparent framework for making choices, it generally fails to provide for sufficient collaboration among the lead management agencies, and it supports neither a defensible basis for communicating with outside stakeholders nor a strategic basis for communicating with funding agencies or Congress. Most importantly, it fails to either recognize or do anything about all the different reasons why scientists and managers might *not* be allowed to do their jobs, which can cover a broad range from financial limits on available resources to institutional and political constraints or conflicts with existing economic interests. These reasons help to explain the relative lack of progress to date in developing an effective recovery framework for Gulf of Maine Atlantic salmon.

In contrast, a SDM approach starts with values, not science, and links recovery activities to understandable, carefully articulated objectives. A range of alternatives are constructed and compared: recovery efforts are not focused on developing a single best plan but, instead, on building a range of plans that can be compared and used as the jumping-off point for advancing preferred alternatives based on an in-depth review of their consequences across a range of dimensions. Uncertainty—stemming from both the consequences of management actions and the confidence held in their successful implementation—is addressed explicitly. When information is missing or of low quality, experts are asked to fill in these gaps using their subjective judgments, which in turn serve as the basis for further deliberations and improved understanding of hypotheses concerning possible barriers to recovery and the outcomes of proposed actions. Costs and benefits and risks are compared using common metrics and financial and personnel constraints are introduced, with these limitations serving as the basis for managers to address difficult (but unavoidable) trade-offs.

The goal is to provide insight to resource managers and other decision makers, not to make choices. Adoption of a sound decision-aiding approach does not do away with the difficult choices that lie behind development of any successful recovery framework. However, the hope is that the additional clarity provided through use of an explicit and consistent decision-making framework will permit scientists and decision makers, working together with other parties, to move forward and to incorporate and evaluate additional input from other stakeholders in a systematic and transparent manner that, over time, will foster both trust and collaboration.

In the case of ATS recovery efforts, one of the primary reasons for testing a structured decision-making framework was to encourage improved communication between scientists working with a technical agenda and managers working with a policy or political agenda. To a large degree, the use of an SDM approach has been successful: managers and scientists within each of the three lead agencies were able to work together on a common set of problems, and both intra- and across-agency cooperation were improved by developing consistent criteria with which to evaluate a broad range of proposed recovery activities. Three aspects of the approach were especially helpful: the definition of explicit objectives and sub-objectives to guide recovery efforts, the use of transparent expert judgments to move forward when data was scarce or substantial disagreements existed among participating scientists, and the documentation of discussions relating to each step of the decision-making framework as a vehicle for communicating the results of the workshop deliberations to a wider audience of scientists, managers, and politicians. These benefits continued to play a central role in discussions leading to publication of the March, 2011 “Atlantic Salmon Recovery Framework,” which builds on the earlier workshop deliberations and has been approved by the NMFS, the DMR, and the FWS as well as the Penobscot Indian Nation.

A number of additional considerations will influence the future success of Atlantic salmon recovery efforts in the GoM. From a management perspective, an obvious concern is the various institutional constraints that might encourage managers and scientists at one or more of the three lead agencies to continue to engage in “business as usual.” From a science standpoint, a concern is the success of ongoing efforts to characterize, assess, and report uncertainties in a consistent manner across the different action teams and resource management agencies. This will require additional attention to quantitative analyses as well as the qualitative characterization of uncertainty, with decisions needing to be made at each stage about the appropriate level of precision and the preferred expression of biological uncertainty. From a governance perspective, a concern is the relative risk tolerance of the different management agencies, particularly with regard to the priority given to expenditures across different categories (e.g., conservation hatchery vs. marine survival) and across different types of recovery actions (e.g., mitigation as compared to research). Another unknown is the future success of efforts to obtain supplementary funding for proposed management and research activities directed to assist in Atlantic salmon recovery efforts.

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